LABVIEW Based Monitoring the Engine Control unit

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Abstract: Whether you like it or not (and I think you all should like it), the engine control computer is here to stay. While it does seem like a real pain to have to deal with, it is the key to unlocking the power that engines can deliver, and doing it without mucking up the atmosphere. This article just scratches the surface of ECU operation, but should provide a good foundation for understanding the why and the how of engine control functions. What's the first thing you should take away from this article? That the ECU is your friend! Without it, you couldn't have the clean, powerful, fuel-efficient engines with built-in safety features (for the engine and you) that are expected in today's cars. The second thing is that you should get an OBD-II scanner or data logger. This is even more true if you are out of warranty. Getting the fault codes out of the ECU when there's a problem is the place to start to figure out what's going wrong. Data loggers help even more. Also, modern code scanners will work on any car built after 1998, when all cars sold in North America had to comply with OBD-II. And the last thing to take away (which will be the subject of the next article) is that the ECU is the key to unlocking even more power and performance from our cars. Thus the performance of the enginecontrolling will be illustrated in the LABVIEW simulation software.

I. INTRODUCTION

The ECU is quite a capable device. It can run the engine much closer to the proverbial "edge," where more power is to be found, and do it safely. This is what makes our little cars so capable. The MCS is rated at 100 horsepower per liter, and the JCW cars have almost 130 hp/l. These are large numbers indeed. Compare that to the 2006 Z06 Corvette, which makes only about 70 hp/l, about the same as a Mini Cooper . That's not too shabby. On the Mini, the ECU is manufactured by Siemens. Unfortunately, Siemens, BMW and Mini don't provide any information about exactly how this unit works. Not to worry, however; in the quest for more power, some pretty smart people have been able to infer most of what we need to know about how the Mini ECU works. In this article, we'll spend some time learning about the ECU and engine management. In the next issue, we'll look at some of the options for modifying the ECU to improve performance, and some of

the pros and cons of doing so to help you make an informed decision about whether "More Power" is right for you and how to get it.

II. LABVIEW

LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. The purpose of such programming is automating the usage of processing and measuring equipment in any laboratory setup.

The graphical language is named "G" (not to be confused with G-code). Originally released for the Apple Macintosh in 1986, LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various versions of UNIX, Linux, and Mac OS X. The latest version of LabVIEW is version LabVIEW 2010, released in August 2010.

III. MAKING POWER OUT OF GASOLINE AND AIR

In its most basic form, an "internal combustion" gasoline engine works by mixing gasoline with air, compressing it in the cylinders, and then igniting it with a spark. In the days before the ECU, the gas/air mixture was controlled by the carburetor, and ignition timing was controlled by the distributor. These two components had been optimized over the decades to perform reasonably well. However, in the late 1960s, emissions and efficiency regulations were

enacted that required automobiles to run cleaner and produce better gas mileage. These regulations are the primary cause for the widespread adoption of computer-controlled fuel injection and ignition. So why does an engine require fuel injection in order to run cleanly and efficiently? To answer that, we have to learn a bit about air/fuel mixtures, power, and emissions. Gasoline consists of molecules containing carbon and hydrogen (and a bit of other stuff added to keep valves clean and so forth). When the hydrocarbon molecules are burned in the cylinder, pressure is created that pushes down on the piston to give the engine its go. If you don't have enough oxygen, you can't burn all the gas, and you lose power. Conversely, if you have too much oxygen, it takes the place that gas could occupy, and you lose power. This is a gross oversimplification, but it does illustrate the notion that there is a correct mixture, or ratio, of air and fuel to create the most efficient burn of the gasoline. For gasoline (the number is different for different fuels) this number is 14.7 to 1, and is referred to as "ideal stoichiometry" (don't worry, I won't use that word again). 14.7 grams of air are required to completely burn one gram of gasoline. Some might guess that this is the end of it; all one has to do is design a system that holds this ratio constant, and you're done! Unfortunately, engines, like most things in life (especially the fun ones) are never really so simple. For a lot of reasons, the best power comes on the rich side of the air-fuel mixture (at about 12.5 to 1). And to make matters worse, the best economy comes on the lean side (at a bit above 15 to 1) the fig.1 shows that The ECU exposed: The ECU is next to the air intake. With the cover removed, the wires going into the engine compartment can be seen at the front, and the connector into the passenger compartment at the rear. The computer itself is just below the connectorsIt's getting more complicated.. And we haven't even considered emissions…

IV. EMISSIONS – THE BAD THINGS

When the engine runs rich, there isn't enough air to burn all the gas. This means that the engine will emit a lot of hydrocarbons (usually referred to as HCs, essentially unburned fuel, a signature of poor fuel economy, and a contributor to smog) and carbon monoxide (CO, a poisonousgas). Unfortunately, we can't just run a little too lean because theNOx (oxides of nitrogen, a component of smog) skyrockets past whatthe catalyst can handle if the mixture gets even a little bit lean! Thesechanges are shown graphically in Figure 2. It's this fine window of low emissions that requires the use of computercontrolled fuel injection. No mechanical system can sense whatthe car is doing fast enough to provide real time tuning of the engineso that the engine can be kept in the range where emissions can be keptat low levels. No matter what one thinks of government regulation, theemissions standards

for cars are what have driven the adoption of fuelinjection. But it's not all bad, as without fuel injection, we wouldn't havethe power at our disposal that our little engines can let loose when wepush the go pedal!There are several types, or approaches, to fuel injection, and they differin how they measure the demand of the engine for air, and hence,fuel. While we won't cover them all here, the Mini engine managementfunctions via a control method called "speed-density." The computerknows the engine speed via a sensor that measures crankshaft speed (enginerevolutions per minute), and measures the air density in the intakemanifold via a sensor that measures air temperature and pressure. Theamount of air in the intake is proportional to the absolute pressure dividedby the absolute temperature.This information, along with the driver demand (how far you're pressingthe gas pedal), is enough for the ECU to know what the engine needsin terms of fuel delivery. It calculates away, and figures out when andhow long to hold open the injectors, and when to fire the spark. For whatit's worth, the fact that the car uses Speed/Density fuel injection can helpexplain which modifications require ECU retuning, and which do not.(See the sidebar for more information.)While this sounds pretty simple, it gets messy fast. The way the ECUmanages the injectors and spark is by referencing a bunch of tables in itsmemory (called look-up tables or "maps") to know what to do in each andevery operational condition (and there are many, each with a slightly differentset of rules for running the engine).The ECU has to do all this while making sure that emissions are minimized,while not allowing the engine to run in some way that would leadto engine damage (too hot, too dirty or with too much knock). You canthink of the routines in the ECU that supervise these other aspects as electronicmothers-in-law, nagging the ECU to avoid certain bad behaviors.A modern ECU is very capable at running the engine, and listeningto the nagging at the same time. Most of us just worry about gettingthe most power, but the ECU can't ignore all the rest. Furthermore, itcan adopt different behaviors using its look-up tables, depending on themode in which the engine is operating.

Ignition Timing vs Octane
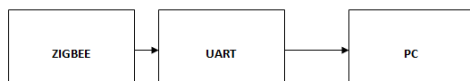
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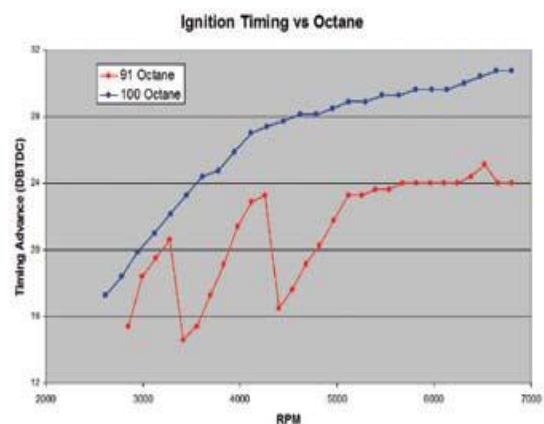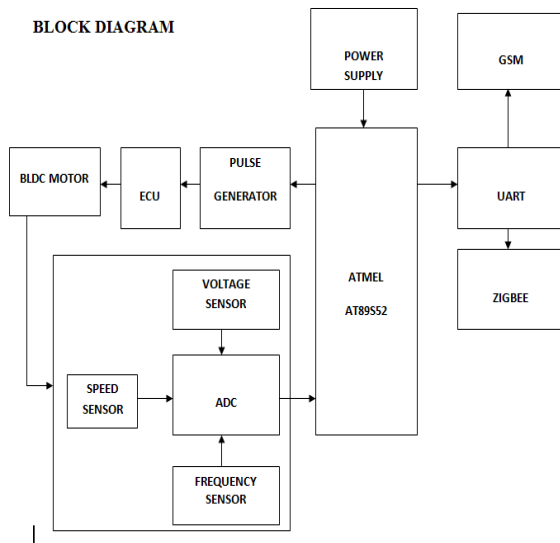
V. MODES OF OPERATION

When you first turn the key and the engine is cold, the coolant is cold, the fuel is cold, the oxygen sensors are cold and the engine just isn't in its happy spot. This is called *cold start mode*. In this case, the ECU has to squirt a different amount of fuel (more) to get the car running than when everything is nice and warm.

RECEIVER SECTION

There is a *warm start mode* as well, when the engine is warm, but isn't firing and the speed is slow, with the crank being turned by just the starter. This mode requires more fuel than standard operation, but not as much as cold start. In the *idle mode*, the engine has to spin at low rpm and keep spinning at this speed when lights or A/C are turned on or off. While keeping idle speed smooth is more complicated than you would first think, we won't discuss it here. Just keep in mind that the ECU keeps track of the engine rpm, the changing load, and keeps the engine speed constant. Under *engine braking mode*, when you've taken your foot off the gas and are decelerating, the ECU stops running the injectors all together, to improve fuel economy. However, most driving is in a *cruise or light load mode* with the car at normal operating temperature. Many refer to this as "closed-loop" operation because the controls on the engine inputs are determined by the engine output which in turn is affected by the engine input (a "closed loop" in computer terms). When the car is running in this mode, the ECU uses the look-up tables to figure out what to do, but modifies thesesettings by looking at the output of the first oxygen sensor, so that theamount of fuel injected can be tuned for best emissions without giving

up much in power.If you're wondering why the ECU modifies the settings, the first reasonis something called tolerance stacking, and this is just the fact that every

engineisn't exactly the same. Parts are not manufactured to precise measures,but instead are manufactured within tolerances to the ideal measurement,and all these variations from ideal add up, or stack.The second reason is engine wear and tear. As the parts wear down,and deposits are built up on the valves, in the cylinders and in the injectors,the engine's behavior isn't exactly the same as when it left the factory,so the look-up tables don't apply exactly.The third reason is variations in gasoline. While it's all called gasoline,the quality and energy content can vary greatly by region, by season, oreven supplier.And lastly, there are variations in ambient conditions. Water vapor inthe air (humidity) which won't burn, displaces air, but the sensors don'tdifferentiate between air and water vapor. So the oxygen sensor in theexhaust pipe looks at the amount of unburned air (fuel?) in the exhaust,and tunes the injection timing to make sure that the right amount of gas is used. This also aids in the efficiency of the catalytic converter, keepingemissions down and our air (relatively) clean. By far the most fun operational mode of any engine is *Wide Open Throttle*. This is when your foot is pressed to the floor, and the tach is swinging to the big numbers as fast as it can. This is (mostly) an open-loop mode of operation, as the best power is made when the engine is running very rich (much more gas than air to burn it), and the output of the oxygen sensor can't be used as it is in closed-loop cruise mode. This is where tuning can provide the greatest benefits to the stock engine, and is mandatory as more invasive modifications are added to your engine.

VI. ENGINE PROTECTION

The ECU does more than just run the engine. One of the most important functions is to protect the engine from unexpected problems, including both mechanical failures and driver errors. The rpm limit is very easy to understand. The engine is built to spin up to some amazing speeds, but when those speeds are exceeded, components start to bend, break, or fail. To avoid this, when the engine hits a pre-programmed rpm limit, it just stops injecting fuel into one or more of the cylinders. You go from a four-banger to a three-banger, and there's no more power to spin the engine faster. It just stops accelerating. But it also protects the engine for over-revving under acceleration. If you hit the rev limit, you'll know it because all of a sudden, it will feel like the engine is broken… but don't worry, it's not! But there is one important aspect of this type of rev limiter to keep in mind. It won't protect the engine from over-revving if you downshift into the wrong gear. Then the momentum of the car is what is accelerating the engine, and all hell can break loose (as well as pistons, connecting rods, valves… you get the idea). So our rpm limiter isn't perfect, but it will protect the engine from excessive acceleration. A second protection system function is pretty easy to understand as well. When gasses are compressed, they heat. That's just the way it is. If the air charge going into the cylinder is already very hot, it can reach temperatures under compression when it can spontaneously detonate, and do this prematurely. This is bad, and will damage the engine. So when the ECU detects that the air temperature in the intake manifold is too high, it will inject

more gasoline than is needed for power generation. It takes a lot of energy to turn the liquid fuel into vapor, and this will cool the air charge. And rich mixtures burn cooler, helping even more. For those who are familiar with water injection, this is just the ECU using gasoline for the very same function: to cool the intake charge, and prevent detonation. This protection system doesn't really kick in for day today operation, but it could become significant if you're doing a lot of work on a dyno, when the car is working hard, and there's no air-flow to cool the intake charge via the intercooler. The most important protection system is based on the knock sensor. It is a microphone that is bolted to the engine block to literally "listen" for the onset of detonation, often called "ping" or "knock." Detonation, or explosion of part of the fuel-air mixture from excessively high pressure or temperature before it has time to burn, is very bad. If it is allowed to get too severe, it will melt or pop a hole in the top of a piston: A very, very expensive event. To prevent this in normal operation, additives are added to the gasoline to increase its octane, and improve its burn to minimize detonation. But it can also be controlled by tuning the engine to increase burn time. So why not just tune the engine to stay away from conditions that lead to knock? Because if Mini did that, the tune would be so conservative that our engines wouldn't be able to deliver nearly the power that is available. So the engine has the knock sensor, and it's tuned more aggressively, so that we all can have much more fun driving our little cars! And this function *cannot* be done without an ECU. When the knock sensor hears the onset of knock, the ECU pulls back the timing on the engine. This delays the combustion, reducing cylinder pressures (but also reducing power and fuel efficiency). Figure 3 shows two timing traces from some testing I was doing on intercoolers. The smooth curve was obtained with 100 octane gas, and the jagged curve was with crappy, California 91 octane gas. Depending on the rpm, over 10 degrees of timing is pulled from the engine! If you're curious, this is from a mildly modified car. In talking to tuners and data hounds, pretty much every MCS can have some degree of timing retard when operating at WOT on pump gas. This isn't bad, but it does mean that there is power to be had by increasing the octane of the gas you are running. If you do have an MCS and access to some high octane gas fortrack use, go mix a tank of 50/50 with premium and the high octanejuice. I think you may find a pleasant surprise.

Other ECU functions

The ECU doesn't just control emissions and protect the engine. It alsoworks on several other important systems in our cars, and will have moreto do in the turbocharged engine used in the 2007 models.Our current Minis use an electronic throttle body, sometime referredto as "drive-by-wire." This is because there is no cable physically linkingthe gas pedal to the throttle body. The ECU takes the driver demandfrom the gas pedal, goes to a look up table in memory, and dependingon some other variables (like engine rpm) tells the throttle body howmuch

to open. The ECU also looks at sensor measuring pressure on theintake path in order to optimize the throttle body opening in responseto changing load (such as when going up and then down a hill, or havingthe A/C cycle on and off).Traction and stability control functions are shared between the ECUand the anti-lock braking and stability control systems. The wheel speedsensors for the ABS system are sent to the ECU over a special high speednetwork connection (called the CAN bus). If the ECU detects wheelspin upon acceleration, it will intervene and modify timing, or throttlebody position, or both, to temporarily reduce power output. In stabilitycontrol situations, the ABS/ASC/DSC module may request powerreductions from the ECU to prevent spins or loss of traction duringcornering (and this is why you should turn the systems off when you areon the track! They will slow you down when you least want it.)The ECU also performs emissions monitoring functions as well. Whilemany are vocally opposed to the on-board-diagnostic functions (abbreviatedas OBD-II), I am quite a fan. Many are "down" on the emissions systemsbecause they think they rob power from the cars. While the catalytic converterdoes restrict exhaust flow somewhat, the benefits of the system greatlyoutweigh any impact for all but pure race cars.The OBD-II standard is what allows all those code scanners and dataloggers to work, as all car manufacturers must support basic sensor data access.If you've ever had the dreaded dash light come on with the little engineon it indicating a problem, those code scanners can let you know what theengine is reporting, greatly helping to troubleshoot the issue. (You can alsopre-scan the car before taking it in to the dealer for service if under warranty,as a little check on the feedback you get from the service techs!) The OBDIIlegislation is also what mandated the ability to upload improved enginemanagement maps for already-sold cars, creating the very back door thatmany tuners use to boost the output of our cars even further.The list of other ECU functions is nearly endless. It controls the radiatorfans, and can turn off the alternator under peak power demands. Itprovides engine speed information to the instrument cluster, and talksto the security system that makes sure that your key is in the ignition toreduce the chance of theft. It communicates with the automatic transmissioncontroller to choose when to shift, and runs the cruise controlsystem to allow you to relax on long drives. It even measures vehiclespeed to automatically increase the stereo volume as you speed up!And it will be asked to do more. While I don't know what ECU will bechosen to run the 2007+ engine, it will govern the boost and turbo controlfunctions on the MCS, and will control the variable valve timing on both the Cooper and the S. It will also probably control the electric water pump that will free up yet a few more horsepower in the new engine.
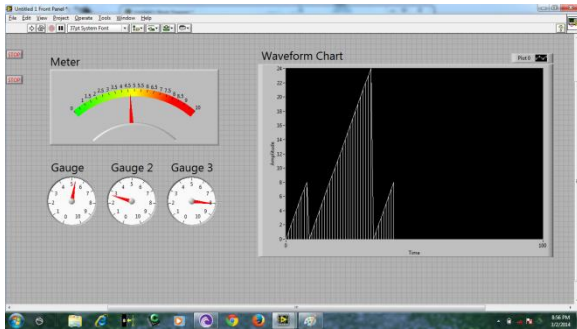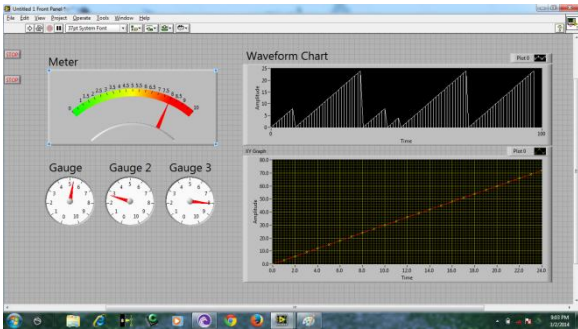
VII. CONCLUSION

Inputs and Outputs

The ECU "sees" by looking at sensor values (inputs), and it "acts" by setting or changing Outputs. Following are the most important sensors and outputs in the Mini.

a) Input Sensors

- ECT, Engine Coolant Temperature: This sensor is used by the ECU to determine if cold operation maps are used, or if normal operation maps are used.
- T-MAP, Temperature and Manifold Absolute Pressure: This sensor is mounted on the intake manifold on both the Cooper and the S. The ECU uses these signals to calculate air density in the intake manifold; the temperature reading may be used for fuel enrichment in the case of very hot intake air temperatures.
- MAP, Manifold Absolute Pressure: This sensor is only found on the S, and measuresthe manifold pressure before the supercharger. It is used for feedback control of thethrottle body opening.
- Crankshaft Position Sensor: is used for determining rpm, for ignition and fuel injectortiming calculation.
- Camshaft Position Sensor: is used for ignitionand fuel injector timing calculations.
- Knock Sensor: is used to adjust timing when the onset of knock is detected.
- First Oxygen Sensor: is used for fuel mixturecontrol at cruise and light throttle.
- Second Oxygen Sensor: is used to checkcatalytic converter operation efficiency,and is not used in engine control.

- Driver Demand (gas pedal) sensors: Two potentiometer sensors in the electronicgas pedal are used to measure driver demand the two are checked against eachother to make sure the signals are not corrupt.
- TPS, Throttle Position Sensors: two potentiometer sensors are housed in the throttle
- body to monitor throttle body opening, and are checked against each other tomake sure the signals are not corrupt.Oil Pressure Warning Switch: activates the dash idiot light to warn of low oil pressure.

b) Output Controls

Fuel Injector outputs (four) control the operation of the fuel injectors.Ignition Coil outputs (two) control firing of the coils.
Throttle Body controls (four) run stepper motors that open and close the throttle bodies.

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